

The Role of Perception and Motor Programme in Deliberate Mirror Writing

Examination Number: B008142

MSc

The University of Edinburgh

2011

I have read and understood The University of Edinburgh guidelines on Plagiarism and declare that this written dissertation is all my own work except where I indicate otherwise by proper use of quotes and references.

Abstract

This study investigated the case who had been doing deliberate mirror writing for a long time. And hope to have an insight to the underlying mechanisms. The perceptual hypothesis and motor programme hypothesis were tested with four experiments. The results of mental rotation task of alphanumeric characters showed that KB had no difference in reaction times between forward characters conditions and backward characters conditions while control group needed longer time to respond to backward characters. Moreover, in the task of mental rotation of body parts, KB had a significant lower accuracy in hand condition, and fitted the criteria of dissociation between hand and foot conditions. It was suggested that KB's deliberate mirror writing was related to both motor and perceptual processing.

Contents

Abstract	i
Contents	ii
Introduction	1
Method	7
Case K.B.	7
Participants of Control Sample	8
Procedures	9
Experiment settings	9
Stimuli	10
Experiment 1	10
Experiment 2	11
Experiment 3	11
Experiment 4	12
Analyses	13
Experiment 1	14
Experiment 2	14
Experiment 3	15
Experiment 4	16
Results	16
Experiment 1.....	16
Experiment 2.....	20
Experiment 3.....	23
Experiment 4.....	24

Discussion	25
References	32

INTRODUCTION

Mirror writing refers to writing word strings as well as every individual letters of the word in reverse direction. It can be produced involuntarily or deliberately. The involuntary mirror writing was usually seen in patients underwent a brain damage, some of which would force them to write with their non-dominant hand, in young children intermittently when they are start learning to write, or even in young adults writing under unusual circumstances (Schott, 2007). Since the cases reported in the literature with mirror writing were patients who had heterogeneously pathological causes and were divergent in the performance of mirror writing, it was hardly to reach an agreed interpretation of how mirror writing occurs. And consequently leaded to the viewpoint of mirror writing being a complex phenomenon, and would have difference cause on different people (Lebrun, Devreux, & Uleux, 1989; quoted in Della Sala & Cubelli, 2007).

The two major hypotheses for involuntary mirror writing concerned failure related to either perceptual or motor processing.

The first perceptual hypothesis was described by Ortan (1928). In this hypothesis, the “engrams” of letters and words were stored in both hemispheres but in the non-dominant one being as mirror-reversed forms. In the study conducted by Yang (1997), normal right-handed subjects were asked to write real and pseudo Chinese characters in both canonical and mirror-reversed fashions. The result showed that the writing times were shorter in real characters than pseudo characters only when using right hand to write conventional forms and when using left hand to mirror write. This “character-superiority effect” complicated by interaction of writing hands was interpreted as a support for the hypothesis of both normal and mirrored engrams stored in the brain.

When children begin learning to read and write, the hemispheric dominance of language had not yet been well established, and therefore resulted in writing occasionally extracting mirrored

engrams. This would explain why children were observed mirror writing with their dominant hands, and they usually did not perceive their mirror writing (Schott, 2007). The pathological mirror writing, on the other hand, was a result from failure to inhibit the trace of mirror representations guiding their writing (Gottfried, Sancar, & Chatterjee, 2003). In consequence of that, the majority of patients in literatures performed mirror writing with their non-dominant hands (see reviews in Della Sala & Cubelli, 2007).

The second hypothesis suggested the occurrence of mirror writing as a failure in transferring motor programme when writing with non-dominant hand. As the symmetric design of our body, the natural bimanual movement of the upper limbs would be two arms (hands) moved in an opposite direction (Swinnen & Wenderoth, 2004). Meanwhile, the same writing motor programme for one hand being applied on the other hand would produce the movements in the opposite direction. Some researchers believed that both hemispheres stored the scripts for motor conceptions. In this condition, writings with both hands were led by the contralateral pathways (Buxbaum et al., 1993; see Schott, 2007). Other researchers proposed that there was a unitary motor programme stored in the writing dominant hemisphere. When writing with the non-dominant hand, it invoked an ipsilateral control which, in addition, required a transformation of motor scripts to conduct the conventional writing (Chan & Ross, 1988). From these two views, unintentional mirror writing was caused by suppressing failure of non-dominant hemisphere releasing motor controls or, alternatively, by the inability of direction transformation.

In addition, centrifugal movements of the arms and hands were thought to be more natural than centripetal movements (de Lange, Helmich, & Toni, 2006; Schott, 1999). Meantime, studies with normal control subjects showed that left-handers preferred mirror writing more than right-handers since the mirror writing movements were writing start from right to left (Schott & Schott, 2004; Tucha, Aschenbrenner, & Lange, 2000; Yang, 1997). Furthermore, it was observed a prevalence of mirror writing in right handed patients writing with their left hands

(Angelillo, De Lucia, Trojano, & Grossi, 2010; also see reviews in Della Sala & Cubelli, 2007). That is, those patients found it straightforward to conduct writing in outward movements.

Other hypothesis associated mirror writing with spatial disorientation (Heilman, Howell, Valenstein, & Rothi, 1980), suggesting mirror errors in unintentional mirror writing were resulted from right-left confusion. A more recently proposed theory by Della Sala and Cubelli (2007) intended to draw a unitary interpretation for involuntary mirror writing. In this theory, “directional apraxia”, the information of word shapes and the specific working direction were stored separately. When conducting writing behaviours, it required an integration of the two pieces of information to produce a correct writing. As a result, the occurrence of unintentional mirror writing would be caused either by configuration not being specified yet in young children, or by damage to the trace of this information in patients’ brain. The interpretation of this theory would predict no prevalence neither in handedness nor the writing directions of the associated languages.

Since the pathological cause of mirror writing would be more diverted between patients, and the occurrence and associated “symptoms” could vary with times and sometimes just fade away, it resulted in restrictions for investigating adult mirror writing.

This research had an opportunity to approach to a case who has been produced deliberate mirror writing for a very long time. This case, KB, started training himself to do the mirror writing, for fun at the beginning, and resulted in mirror writing and mirror drawing being a distinguishing feature in his art works. KB’s mirror writing/drawing started from his pupil time, and had lasted for decades.

The aim of this study is to investigate the relation of the perceptual and motor processing with deliberate mirror writing, and hope that the understanding of underlying mechanisms of intentional mirror writing would give an insight to the cause of unintentional mirror writing.

Four tasks were included in this research.

Firstly was to test the perceptual hypothesis. That is, whether there were mirrored engrams stored in the brain and the deliberative mirror writing was to extract these engrams to write them down. Although it was claimed by KB himself that he was unable to read the words in the mirror representations, besides, mirror reading was rarely reported with mirror writing in patients and those who wrote in mirror fashion were hardly able to read their own writing. However, there were at least some reports of patients had accompanied mirror reading with their mirror writing (e.g., Gottfried et al., 2003; Moris, Quirce, Berciano, & Pascual, 1997). Therefore, it was still interesting to investigate this question on KB, since he had practiced mirror writing for such a long period. As tremendous exposed to mirrored formed stimuli every time he conducted mirror writing, it would be easier for him to show an effect on perceptual processing related to mirrored engrams if there was any. It could be that the existence of mirrored engrams might not be strong enough to overcome his well-functioning normal reading and to make him able to mirror reading.

The classical paradigm of Stroop's task (Stroop, 1935) had been widely used in psychological testing to investigate the ability of suppressing inconsistent information. In this paradigm, colour words were shown in either the congruent ink colour or a incongruent different ink colour, such as word "green" printed in red ink. Participants were asked to speak aloud the name of the ink colours while trying to ignore what the word was. Because in reading a word, semantic processing was more automatically than processing the ink colours, participants needed to inhibit the semantic activation first, and then report the ink colour. It, therefore, resulted in a longer response time for naming the ink colour for a incongruent colour word, which was referred as semantic interference. Meanwhile, naming the ink colour for the congruent colour word would perform a semantic facilitation. The prolonged reaction times for naming the colour of incongruent word was so called "Stroop's effect".

The present research would like to use the Stroop's task to examine whether the mirrored

existed with the performance of deliberate mirror writing, by modifying some stimuli to the mirror-reversed version. It was assumed that, in normal people, there would be smaller semantic interferences and smaller semantic facilitations in the condition of words being reversed, since this kind of stimuli would not trigger an automatic semantic processing like normal words, thus reduced the Stroop's effect. On the other hand, if the mirrored engrams were existing to benefit the mirrored writing on KB, the reversed colour words would not, or in a smaller degree, reduced the Stroop's effect like in normal people.

In addition, since there were literatures discussing the difference in processing of single letters and whole words (Gottfried, Sancar, & Chatterjee, 2003; Della Sala & Cubelli, 2007; Koriat & Norman, 1989), this study would also include the Navon's task (Navon, 1977). In Navon's task, stimuli used compound letters (global letters) consisted by either congruent or incongruent smaller local letters. The effect of this task came from the global letters processed prior to local letters, thus would lead to facilitation or interference when judging what small letters were with consisted global letters were congruent or incongruent respectively. This design would allow the using of single letters as stimuli to explore the effect of reversing letters base on the same logic as in Stroop's task.

To test the existence of engram contributing to deliberate mirror writing might be like an instinct. However, it was not for sure that the mirrored engrams would necessarily trigger the semantic processing.

In addition to patients and children, involuntary mirror writing would also occur in healthy adults under unusual conditions such as writing on a sheet of paper placed against the undersurface of a table. Under this condition, to write conventional words would need to overcome the spatial confusion and was related to the process of conscious mental rotation (Della Sala & Cubelli, 2007). Furthermore, as "not to produce mirror writing under the situations of spatial confusion" was referred as a mental rotation solving task, producing

deliberate mirror writing might require skill of mental rotation if it was a perceptual related processing.

Researches on mental rotation task of letters and non-verbal objects had established a pattern of reaction times of mental rotation processing, of which reaction time increased with the increasing of stimuli rotated angle departed from the upright position (Cooper and Shepard, 1973; Overney & Blanke, 2009; Shepard & Cooper, 1971; Vinckier et al, 2006). The interpretation of this reaction time pattern indicated the requirement of imaging the image as been rotated to angle matched to the stimulus to be judged. Moreover, previous studies using mental rotation task on letters had showed that judging a letter as mirror-reversed took longer reaction time than judging a letter as normal (Cooper & Shepard, 1973; Corballis & McMaster, 1996). The result might be because people are usually much more familiar with canonical letters. Therefore, when judging a letter as normal or reversed, it would take an examination firstly on whether the stimulus was normal or not, then judging it as reversed if it was not “looked as normal”.

Including an alphanumeric character mental rotation task on the investigation of KB’s mirror writing would consider three possible results. Firstly, if there were two engrams represented the reversed forms of each other, and KB was more likely to trace both engrams which might let him to skip the “this was not a normal character” process when judging to a reversed stimulus, thus showing a decrease of reaction time. Secondly, the mental rotation of characters was related to the production or non-production of mirror writing which KB had practiced in highly frequency. It would result in better performances than the control group. Thirdly, in contrast to the second view, it was also possible that differentiating the mirror-reversed or normal stimulus was hard for KB because both of the engrams were often activated when KB did mirror writing. Consequently KB was too used to dealing with both forms of letters simultaneously, which made him less sensitive to tell whether a letter was normal or mirror-reversed.

To test the motor program hypothesis, the present research would use the mental rotation task as well, with stimuli of body parts. Similar to mental rotation of characters or general objects, judging the laterality of body images required imagination of stimulus rotated to the correspond orientation to match the view of the imaged presented. Past researches had showed the involvement of motor cortex neural activation in the correspond hemisphere (de Lange et al., 2006). And others also presented that neural damage or lake of the associated body parts would result in a failure of imaging the body movements and performed longer reaction times for laterality judging (Fiorio, Tinazzi, & Aglioti, 2006; Funk & Brugger, 2008; Overney & Blanke, 2009). Therefore, corresponding to the mental rotation of characters, two kinds of possible results would be expected. The first one was that as being frequently practice with specific motor programmes, a better performance on imagination of hand movements would be hold. This prediction would favour the view of contralateral controls of motor program. The other possibility takes the view that a singular motor programme control for the conventional movement of dominant hand, and conducted motor scripts in a mirrored direction to the non-dominant hand if without a transformation. Therefore, moving of either hand would involve the same shared motor programme. Consequently, KB would be less sensitive to the side of his imagination of hand movements in the task.

METHOD

Case KB

KB is a 66 year-old male from Germany. He was a professor in a university retiring last year and also an artist of mirror writing and mirror drawing. KB has showed his ability to do either conventional or mirror writing with both hand working together or separately, and uses this skill in drawing as well. His score on Edinburgh Handedness Inventory (EHI) (Oldfield, 1971) was -64, which would suggest him as left handed. However, KB claimed to learn to write with his right hand in school as he remembered.

KB's practice of mirror writing started when he was about nine years old. He found occasionally that he was able to write with both hand together, with his left hand conducting in the opposite direction to his right hand and resulted in the writing of mirrored fashion. Since then, he practiced a lot the skills of writing in different fashion, even like words upside-down, with both of his hands. Asking KB to read the mirrored words and sentences, however, would be a difficult task for him and he was just giving up.

Participants of Control Sample

Twelve participants were matched on gender and age (range from 56 to 75 with mean=66.2), and reported themselves as mentally and physically healthy. Ten of the participants were judged as strong right handed, with scores higher than 69, and mean score 89.6. One participant was judged as less strong right handed (EHI score=43), and one participant with no preference of handedness, with EHI score= -17.

Because of the restriction of the time line on this project, data of control group had to be recruited before the case came to the lab to have his EHI score, handedness of control sample were not well matched. However, in control group, correlation between EHI score and all tasks performance put the analysis of single-case difference were unrelated or only slightly correlated ($r = -0.23$ to 0.18).

In addition, KB had German as his native language while our participants in the control group were all from Scotland and claimed themselves as native English speakers. However, it should not draw much concerns since the stimuli used in this research were: in experiment one, general, non-verbal pictures of hands and feet; in experiment two and three, numbers and letters that existed both in German and English. For the colour words used in the Stroop's task (experiment 4), there were two versions of stimuli in order to adapt for participants' first language (details described in the stimuli section). Therefore, if there would be any difference between KB and controls observed in the data, it should be the real effect associated with KB's

ability of deliberate mirror writing, instead of the difference of their native languages.

Procedure

The experiments were conducted with one participant at a time. The experimenter would firstly explain the whole procedure as well as each experimental task, and participants would understand their rights of withdrawing from the experiment before giving their oral consent. This research was approved by the ethical committee of Psychology Department in University of Edinburgh. The four tasks would be done in one session in the order as from experiment one to four stated below, concerning the impact of fatigue and task difficulties. There were short breaks between tasks. After completing the four tasks, participants would fill the EHI questionnaire.

Experiment Setting

The experiment was conducted by a computer with a (15 inches) CRT screen and presented with E-prime 2.0 programme package. Participants sat at a distance of 50 cm from the screen, and would be making their responses by pressing buttons on a response box for the first three experiments, and by speaking to a microphone in the fourth experiment.

For the whole experiments, there was a black card board placed under the chin rest, which was used to prevent participants from watching their own hands. This setting was in order for making sure that participants would use mental imaginary in the task of mental rotation of body parts. And as the participants were asked to use one finger of each hand to press the buttons as quick as they could, their hand was therefore pretty much kept in the same position during the task.

Stimuli

Experiment 1: Mental rotation of body parts

Realistic pictures of hand and foot were taken in four different views, which were back, palm, thumb and pinkie. Each view of images were also rotated clockwise in 60 degrees step, and would have six different angles of rotation, namely, 0°, 60°, 120°, 180°, 240°, and 300° (Figure 1).



Figure 1. Examples of stimuli in experiment 1 (body part rotation task). From left to right were views of pinkie, thumb, palm, and back.

Left side stimuli and right side stimuli were mirror imaged from each other. This made a total of 48 pictures for hand and 48 pictures for foot. Trials of hand and foot were showed in separates blocks. And there were four blocks for each effectors, ordered as hand-foot-foot-hand-hand-foot-foot-hand, resulted in 384 trials in total.

In each block, 48 pictures would randomly show on centre of the screen with the largest width 6.2cm, corresponding to 7.1 degrees of visual angle. In each trial, a picture was presented after a 250 ms fixation, and until participants made the response. Participants had to press the leftist button with their left hand if they judged the picture as left hand/foot or press the rightist button with their right hand if they judged the picture as right hand/foot.

Experiment 2: Mental rotation of characters

Asymmetrical alphanumeric characters were chosen in order to manipulate their reflection. There were four types of stimuli, two uppercase letters, “J” and “R”, and two Arabic numerals, “2” and “7”, all used the word form of Times New Roman. These characters could be shown either canonically or in mirror-reversed image. Similar to experiment one, stimuli could be presented in six different rotating angles (0° , 60° , 120° , 180° , 240° , and 300°) clockwise from upright.

Forty-eight different stimuli would repeat five times and were presented in a random sequence. Therefore, there were 240 trials in total and it was divided into four blocks. In each trial, a character was presented after a 250 ms fixation, and until participants made the response. The characters would show on centre of the screen with the longest axis of 3.2cm, which corresponded to 3.67 degrees of visual angle. Experimental task was to judge whether the character was canonical or mirror-reversed. Participants were asked to press the button on the right side with their right hand when judging the image as canonical, and press the button on the left side with left hands when they thought it was mirror-reversed.

Experiment 3: Navon's task

Capital letters E and S were chosen for the stimuli in this task. Global compound letters E and S could be shown in canonical or mirror-reversed way, and were consisted by smaller local letters either Es or Ss. No matter the global letters were canonical or mirror-reversed, the local letters of consists were always printed forwardly (Figure 2). The longest axis of global letters was 3.3cm, corresponding to 3.78 degrees of visual angle. Each type of stimulus would show 10 times, making 20 trials in each condition. A total of 80 trials were done in one block.

In each trial, a random stimulus appeared on the centre of the screen after a 250 ms fixation, and would disappear once participants made a response. Participants needed to judge whether the local letters were Es or Ss, and pressed the left button to respond to when the local letters

were Es, and pressed the right button to respond to when the local letters were Ss. No global judgment was included in this study.



Figure 2. Examples of stimuli in experiment 3 (Navon's task). Stimuli on the left side were canonical conditions, on the right side were mirror-reversed conditions, on the top were incongruent conditions, and on the bottom were congruent conditions.

Experiment 4: Stroop's colour naming task

The words and colours used in this experiment were red, green and blue. In order to get a largest semantic interference to ink colour naming, words of participants' first language were used. Therefore, for all the participants in control sample, who were all English native speakers, the words used were "red", "green", and "blue". The experiment version for the case KB, on the other hand, used German words "rot", "grun", and "blau".

Words could be showed in either canonical or mirror-reversed way, with the same colour of ink, which referred to consistent conditions, or either different colours of ink, which referred as inconsistent conditions. In order to balance the trial numbers of consistent and inconsistent conditions, stimuli of consistent colour pair were presented double times as of stimuli of inconsistent colour pair. There were 30 trials under each condition, and a total of 120 trials were divided into three blocks.

The words were presented on the centre of the screen, extending from 2.2cm to 4.9cm depending on different word lengths, and the corresponding visual angles were from 2.52 to 5.61 degrees.

In each trial, a random stimulus appeared after a 250 ms fixation, and would disappear once the

microphone detected a voice. The microphone was standing in front of the participant to record the reaction time. Participants were asked to speak the colour of the ink aloud as soon as possible. Meanwhile, the experimenter was sitting beside the participant to code their response (named colour) into the computer programme by pressing the buttons on response box. Moreover, the experimenter would monitor how the microphone reacted to participants' speech. That is, if the stimulus on the screen did not disappear when the participant said the colour, or if the stimulus disappeared because of noise other than colour naming, the experimenter would record the trial as an invalid trial.

Analysis

For all the experiments, the data from control sample were firstly analysed with repeated measures analysis of variance (ANOVA). This was to confirm that the pattern of mental rotation task and the Stroop's or Navon's effect described by previous literatures were also able to be observed in this study.

The analysis of KB's data compared to the control sample would use the programmes either DISSOCSBAYES designed by Crawford and Garthwaite (2007), or BTD_cov and BSDT_cov by Crawford, Garthwaite, and Ryan (2011). Choose of which programme(s) depended on whether there was a covariate(s) to put in.

In this study, for all of four experiments, analyses would have two set of data and to be referred as scores of task X and scores of task Y. The programmes would firstly estimate the distributions of the controls' data for the tasks, and then investigated whether KB's performance were statistically significant out of the distribution on both of the tasks. It also provided 95% confidence interval (95% CI) for the probability of people from normal control sample would perform the score more extreme than the case (one-tailed probability). Secondly, it would examine whether there was a significantly larger/smaller contrast between task X and task Y observed on the KB than on controls. This research considered age as a possible

covariate.

In each analysis, correlations between age and performance of task X and task Y were calculated. If one of the correlations was greater than 0.3, age would be taken as covariate and BTD_cov and BSDT_cov were used for the analysis (Crawford et al., 2011).

Experiment 1

Trials with RT longer than 10 seconds were treated as non-responded and removed prior to all the analysis. Both accuracy rates and reaction times were used in the analysis of results, and only the correctly responded trials were considered in the RT analysis. Since the distribution of the reaction times was highly positive skewed and there were missing values to be dealt with, logarithmic transformation was applied to the reaction time data.

The missing values were caused by some participants having all the trials incorrect and/or treated as non-responded under some conditions. In order to take both subject difference and effect of all the associated variables into account, formula proposed by Winer (1962) was used to estimate these missing data. The replacing values were calculated as the mean of appropriate participant plus the mean of associated condition minus the grand mean.

Analysis of the control group data for both accuracy and logarithmic RT used a four-way repeated measure ANOVA with effectors (hand, foot), side (left-side stimuli, right-side stimuli), rotation angle (0°, 60°, 120°, 180°, 240°, 300°), and view (back, palm, thumb, pinkie) as within-subjects factors.

To compare KB's performance with controls, accuracy rates for hand and foot stimuli, collapsing the variables of side, rotation angle and view, were entered as task X and task Y. Analysis of logarithmic RTs used the same method as accuracy rate.

Experiment 2

As in experiment one, trials with RT longer than 10 seconds were treated as non-responded and

removed prior to all the analysis. Both accuracy rates and reaction times were used in the analysis of results, and only the correctly responded trials were considered in the RT analysis. Reaction times were logarithmic transformed because the distribution was positive skewed. Furthermore, missing values were replaced by the formula described in experiment one. Analysis of the control group data for both accuracy and logarithmic RT used a three-way repeated measure ANOVA with reflection (canonical, mirror-reversed), rotation angle (0°, 60°, 120°, 180°, 240°, 300°), and stimulus type (2, 7, J, R) as within-subjects factors. The analysis of KB compared to control group took both the accuracy rates and logarithmic RTs. Collapsing the variables of rotation angle and stimulus type, data of canonical characters were entered as task X and data of mirror-reversed characters were entered as task Y.

Experiment 3

Trials with RT longer than 5 seconds were treated as non-responded and removed prior to all the analysis. Accuracy rates were expected to present a ceiling effect, therefore, only reaction times were used in the analysis. And incorrect responses were also voided from the data used for RT analysis.

Reaction times of control group were analysed by using a two-way repeated measures ANOVA, with reflection (global letter was canonical or mirror-reversed) and consistency (consistent vs. inconsistent) as within subject factors. In order to have a more robust analysis to outliers, median was chosen to present data's central tendency. In addition, in order to consider the responses of both of stimulus types (i.e., local letters were Es or Ss), medians of both stimulus types for each conditions for each participant were computed firstly, and the two medians were then averaged to present the RT of the condition for the participant.

The analysis of KB compared to control group would take the difference of reaction times between consistent and inconsistent conditions. The RT difference under condition of canonical global letter was referred as score X. And the difference under condition of

mirror-reversed global letter was referred as score Y. The main focus of this analysis was to investigate whether KB's score Y was larger than control group or KB's contrast between score X and score Y was smaller than control group.

Experiment 4

Trials coded as invalid records by the experimenter during the task and trials with RT longer than 5 seconds were removed prior to all the analysis. Only reaction times were used in the analysis of result as accuracy rates were also expected to present a ceiling effect. And incorrect responses were also voided from the data used for RT analysis.

Reaction times of control group were analysed by using a two-way repeated measures ANOVA, with reflection (canonical, mirror-reversed) and consistency (consistent, inconsistent) as within subject factors. As experiment three, medians of three different stimulus types (i.e., ink colours being red, blue, and green) for each condition for each participant were computed firstly, and the three medians were then averaged to present the RT of the condition for the participant.

The analysis of KB compared to control group would take the difference of reaction times between consistent and inconsistent conditions. The RT difference under condition of canonical colour words was referred as score X. And the difference under condition of mirror-reversed colour words was referred as score Y. The main focus of this analysis was to investigate whether KB's score Y was larger than control group or KB's contrast between score X and score Y was smaller than control group.

RESULTS

Experiment 1: Body part rotation

Seventy-five trials, accounted for 1.5% of data, with RT larger than 10 seconds were removed prior to all analyses, and 33 (2.64%) missing data across participants were replaced for reaction time analysis.

Analyses of control data

The plots of accuracy rate and reaction times of control group were showed in Figure 3A and 3B. Four way ANOVA of accuracy rate displayed the significant main effect on angle ($F(5,55) = 3.57, p < .01$). Post hoc analysis showed the accuracy of angle of 180 degrees was smaller than 120 and 300 degrees significantly, and also the accuracy of angle of 240 degrees was smaller than 300 degrees (all p value $< .05$). Main effects of effectors ($F(1,11) = 0.77, p = 0.4$), side ($F(1,11) = 0.32, p = 0.58$) and view ($F(3,33) = 2.17, p = 0.11$) were not significant. Interaction were significant on effectors x view ($F(3,33) = 6.08, p < .01$), angle x view ($F(15,165) = 2.71, p < .01$), effectors x angle x view ($F(15,165) = 3.37, p < .01$), and effectors x side x angle x view ($F(15,165) = 1.78, p < .05$).

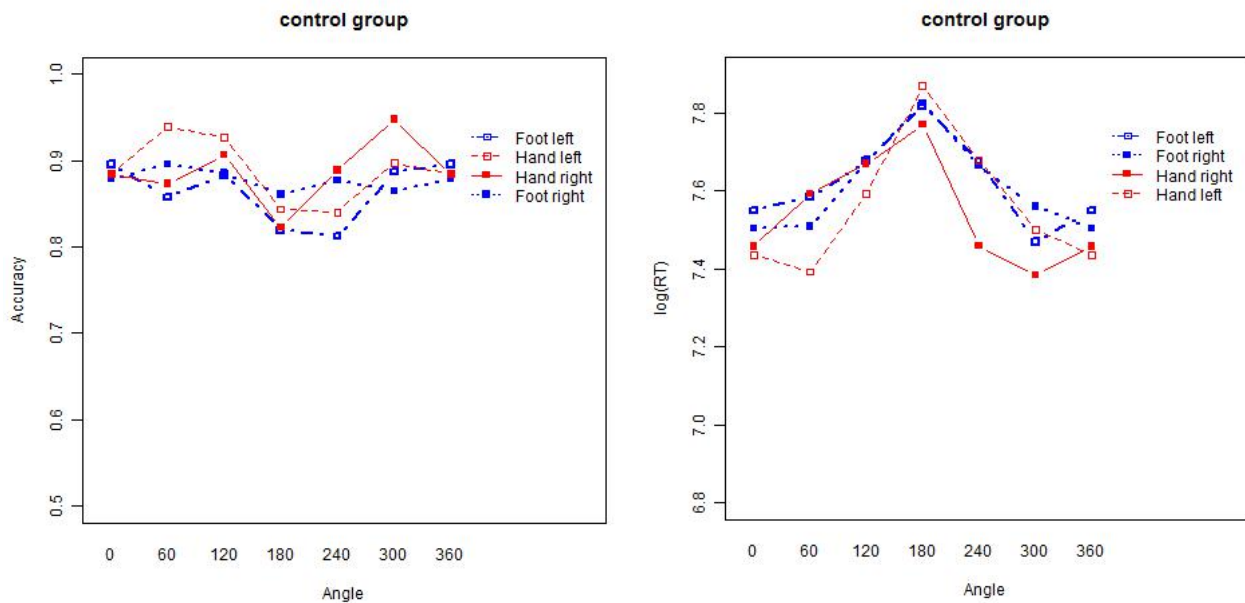


Figure 3A & 3B. Mean accuracy rates and reaction times of control group on mental rotation of body parts plotted as a function of orientation. The points of 360 degree of angle duplicate the points of 0 degree.

Four way ANOVA of transformed reaction times displayed the significant main effect on angle ($F(5,55) = 29.65, p < .001$) and view ($F(3,33) = 11.74, p < .001$). Post hoc analysis showed that, reaction time for the angle of 180 degrees was significantly longer than others, RT of angle of

120 and 240 degrees were longer than angle of 0, 60, and 300 degrees, and RT of angle of 240 degrees was longer than 300 degrees (all p value $< .05$). Main effects of effectors ($F(1,11) = 0.48$, $p = 0.5$) and side ($F(1,11) = 0.62$, $p = 0.45$) were not significant. Interaction were significant on effectors x view ($F(3,33) = 9.43$, $p < .01$), angle x view ($F(15,165) = 8.38$, $p < .001$), effectors x side x angle ($F(5,55) = 3.98$, $p < .01$), effectors x angle x view ($F(15,165) = 5.28$, $p < .001$), and side x angle x view ($F(15,165) = 2.07$, $p < .05$).

Longer reaction times were observed with larger rotation angle from upright positions. The data in control group had shown the pattern expected for mental rotation task.

Analyses of single case

Accuracy rate and RT across hand condition and foot condition were treated as two tasks to enter into the analysis programme. Data of KB were plotted in Figure 3C and 3D.

As correlation between accuracy rate of hand condition and age was -0.68 , and correlation between accuracy rate of foot condition and age was -0.62 , age was put in as a covariate in the analysis. It was found that KB performed significantly worse than control group on hand condition but not on foot condition (Hand: KB's $d = 0.67$, conditioning $z = -2.3$, $p < .05$, 95% CI = 0.05% to 14.93%; Foot: KB's $d = 0.92$, conditioning $z = 0.82$, $p = 0.24$, 95% CI = 52.17% to 93.05%). And his discrepancy between two tasks was significantly larger ($Z\text{-DCCC} = -3.98$, 95% CI on effect size = -5.50 to -1.80 , $p < .010$, 95% CI = 0.00% to 3.61%), revealing a classical dissociation.

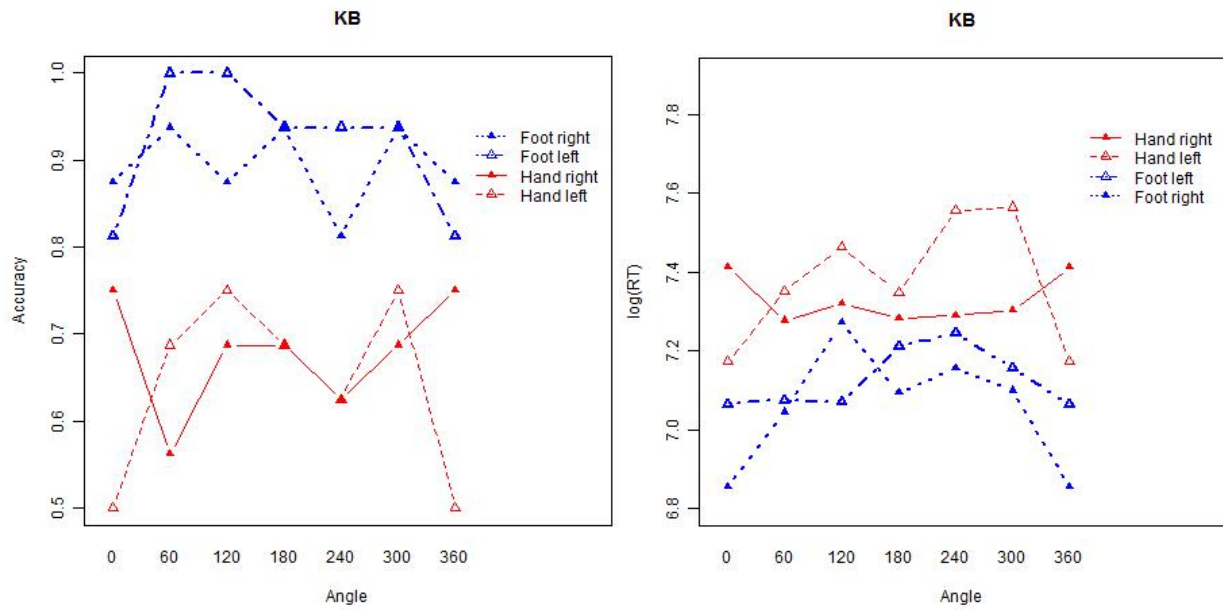


Figure 3C & 3D. 3C: KB's accuracy rates and reaction times on mental rotation of body parts plotted as a function of orientation. The points of 360 degree of angle duplicate the points of 0 degree.

The correlation between logarithmic reaction times of hand condition and age was 0.50, and correlation between accuracy rate of foot condition and age was 0.28. Since one of the task had correlation with age higher than 0.3, age was put in as a covariate in the analysis. No significant effect was found on reaction time analysis (Hand: KB's = 7.36, conditioning $z = -0.66$, $p = 0.19$, 95% CI = 4.31% to 42.01%; Foot: KB's = 7.11, conditioning $z = -1.3$, $p = 0.1$, 95% CI = 1.14% to 30.12%). And his discrepancy between two tasks was significantly larger ($p = .33$, 95% CI = 7.00% to 67.44%), revealing a classical dissociation.

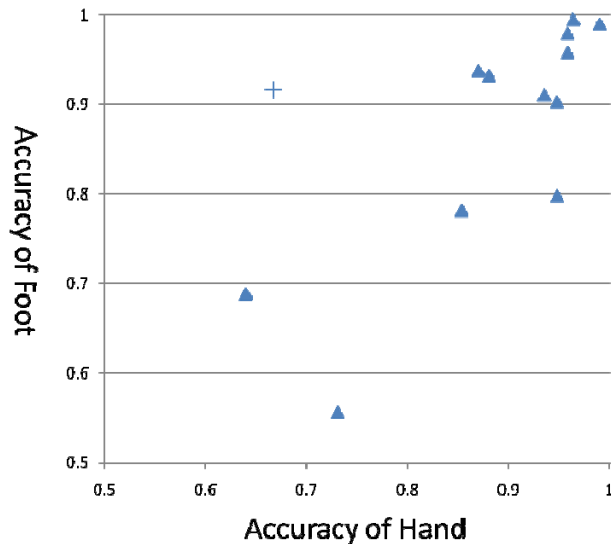


Figure 3E. Correlation between the accuracy rate in hand condition and foot condition. The filled triangles are twelve control samples, and the cross represents the KB's data point.

Experiment 2: Rotated stimuli perception

Nine trials (0.3%) of all data were excluded before analysis because of RT larger than 10 seconds, and 14 (2.24%) missing data across participants were replaced for reaction time analysis.

Analyses of control data

The plots of accuracy rate and reaction times of control group were showed in Figure 4A and 4B. Three way ANOVA of accuracy rate displayed the significant main effect on angle ($F(5,55) = 10.47, p < .001$) and stimulus type ($F(3,33) = 2.99, p < .05$). Post hoc analysis showed the accuracy of angle of 180 degrees was significantly smaller than others, and the accuracy of 120 and 240 degrees were smaller than 0, 60, and 300 degrees (all p value $< .05$). The significant effect of stimulus type was from the lower accuracy rate on stimulus “2”. Main effect of mirror ($F(1,11) = 4.46, p = 0.06$) was not significant. Interaction was significant on mirror x stimulus type ($F(3,33) = 5.30, p < .01$).

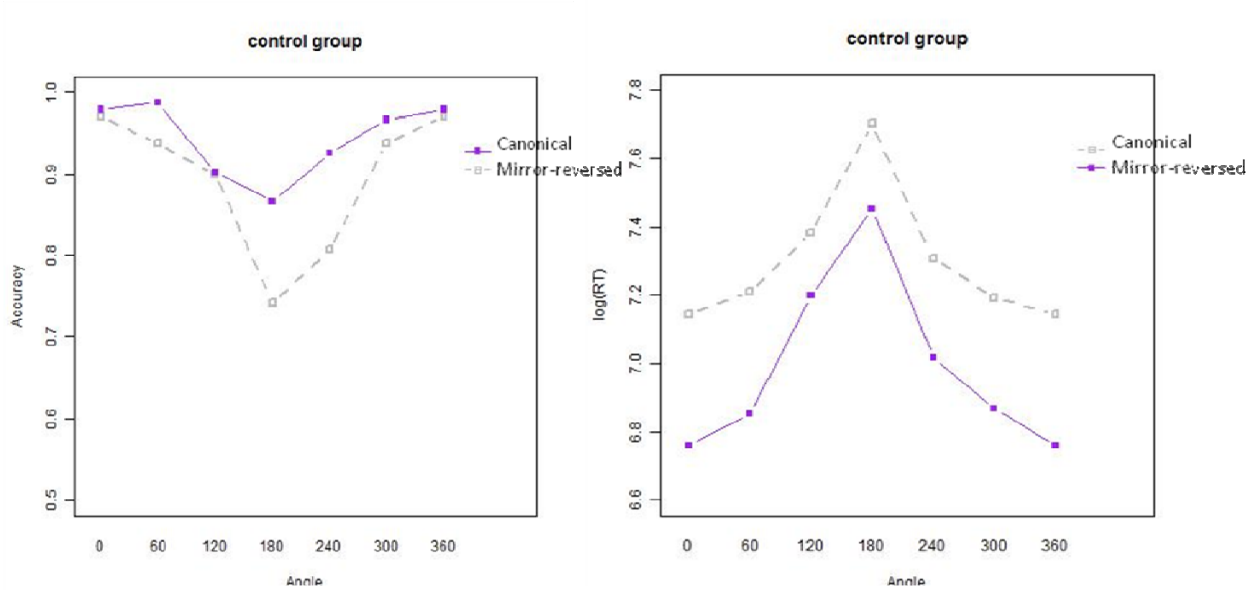


Figure 4A & 4B. Mean accuracy rates and reaction times of control groups plotted as a function of orientation. The points of 360 degree of angle duplicate the points of 0 degree.

Three way ANOVA of transformed reaction times displayed the significant main effect on angle ($F(5,55) = 77.15, p < .001$) and reflection ($F(1,11) = 40.17, p < .001$). For the reflections, reaction times to backward letters was longer than forward letters. Post hoc analysis on angle showed the RT of angle of 180 degrees was significantly longer than others, the RT of 120 and 240 degrees were longer than 0, 60, and 300 degrees, and the RT of 60 and 300 degrees were both longer than the RT of 0 degree (all p value $< .05$). Main effects of stimulus type ($F(3,33) = 2.72, p = 0.06$) was not significant. And the interaction was significant on mirror x angle x stimulus type ($F(15,165) = 2.04, p < .05$).

Analyses of single case

The plots of accuracy rate and reaction times of KB were showed in Figure 4C and 4D. Accuracy rate and RT across for forward conditions and backward conditions were treated as two tasks to enter into the analysis programme.

As correlation between accuracy rate of forward condition and age was -0.68, and correlation

between accuracy rate of backward condition and age was -0.47, age was put in as a covariate in the analysis. KB performed significantly worse in the backward conditions (KB's = 0.67, conditioning $z = -2.1$, $p < .05$, 95% CI = 0.10% to 17.45%) but not in the forward conditions (KB's = 0.91, conditioning $z = -0.38$, $p = 47.15$, 95% CI = 23.96% to 70.90%) The dissociation of the two task, however, was not significant ($p = 0.9$, 95% CI = 0.36% to 31.06%).

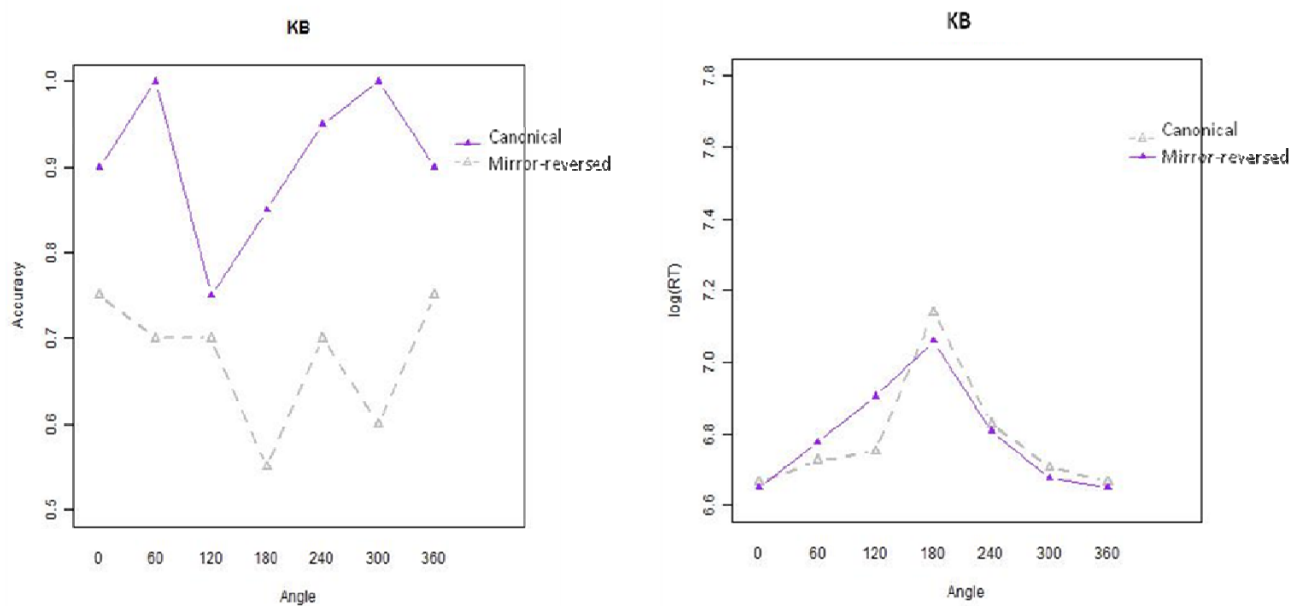


Figure 4C & 4D. Mean accuracy rates and reaction times of KB plotted as a function of orientation. The points of 360 degree of angle duplicate the points of 0 degree.

The analysis of logarithmic reaction times used DISSOC SBAYES without a covariate since the correlation of age and both two task were lower than 0.3. The results showed that KB responded significantly faster to backward characters (KB's = 6.8, $z = -2.26$, $p < .05$, 95% CI = 0.04% to 12.35%). There was no significant difference in responses to forward characters (KB's = 6.81, $z = -1.0$, $p = 0.19$, 95% CI = 5.16% to 40.10%) nor the difference between the two conditions ($p = 0.12$).

Experiment 3: Navon's task

Four trials (0.38%) with RT larger than 5 seconds were removed prior to all analysis. The accuracy rate of all the participants were all above 95%, with a mean of 99.31%, including KB's 96.25%.

Analyses of control data

The analysis of RT in control sample showed neither significant main effects of reflection ($F(1,11) = 4.04, p=.07$) and consistency ($F(1,11) = 0.75, p=.40$) nor significant interaction ($F(1,11) = 2.96, p=.11$) (Figure 5A).

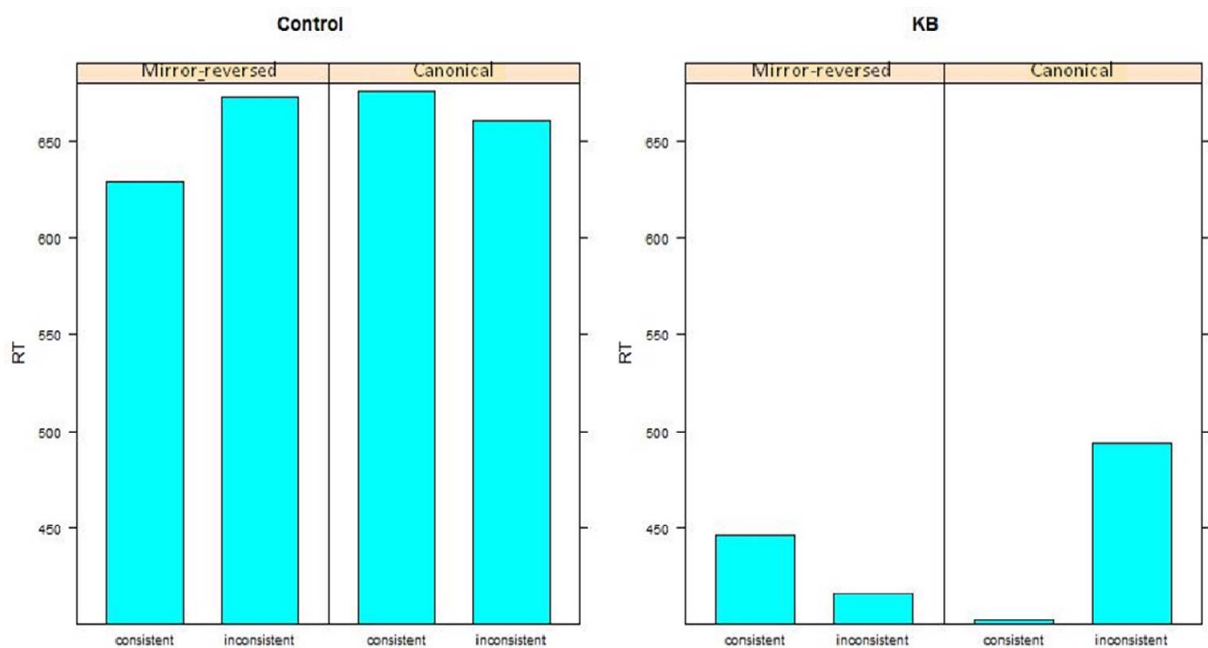


Figure 5A & 5B. 5A: The reaction time of control group revealed Navon's effect. 5B: The reaction time of KB revealed Navon;s effect.

Analyses of single case

It did not make sense to compare KB's data with control group if the control sample did not perform the expected pattern of the task effect. Therefore, the analysis of KB's data employed a

two-way ANOVA but treating reflection and consistency as between subject factors.

There was no significance on main effects of reflection ($F(1,73) = 0.06$, $p = 0.80$) and consistency ($F(1,73) = 0.14$, $p = .71$), but a significant interaction ($F(1,73) = 9.31$, $p < .01$) (Figure 5B). Further analysis showed significant simple main effect of consistency under forward letter condition ($F(1,73) = 5.92$, $p < .05$) but not under backward letter condition ($F(1,73) = 3.53$, $p = 0.06$).

Experiment 4: Stroop's colour naming task

Experimenter coded invalid responses and RT longer than 5 seconds accounted for 63 trials (4.03%), and were excluded before the analysis. The accuracy rate of all the participants were all above 94.74%, with a mean of 98.73%, including KB's 99.12%.

Analyses of control data

The analysis of RT in control sample showed significant main effect of consistency ($F(1,11) = 28.97$, $p < .001$), and significant interaction ($F(1,11) = 10.60$, $p < .01$). No significant main effects of reflection ($F(1,11) = 4.25$, $p = 0.06$) (Figure 6A).

Further analysis showed significant simple main effect of consistency both under forward words ($F(1, 11) = 24.86$, $p < .001$) and backward words conditions ($F(1,11) = 26.95$, $p < .001$).

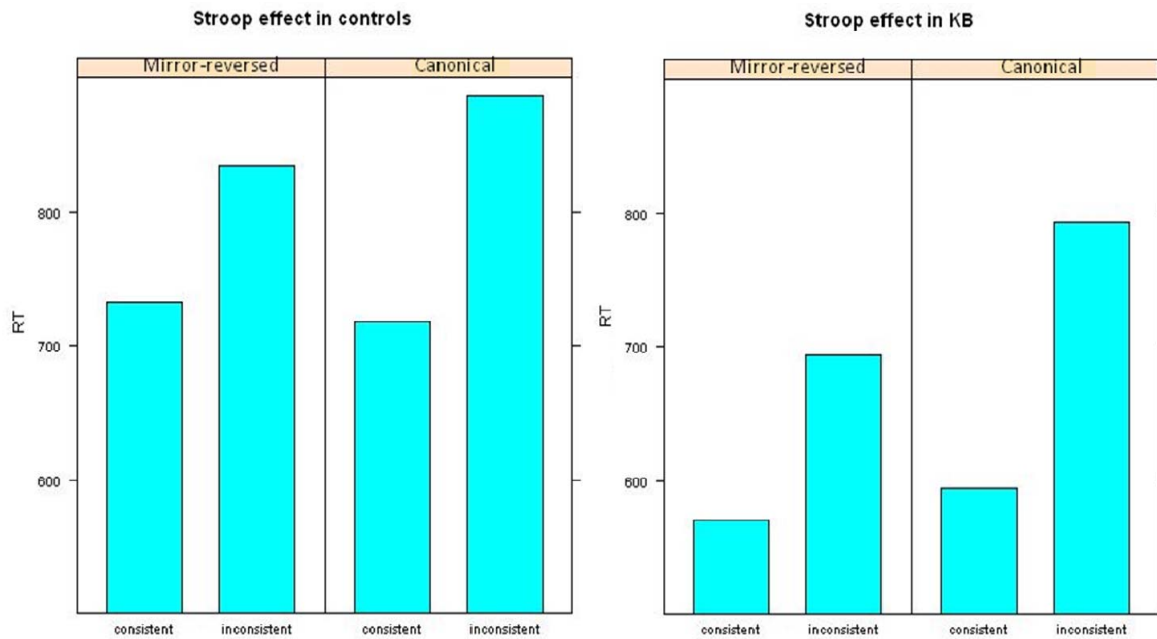


Figure 6A & 6B. 6A: The reaction time of control group revealed Stroop's effect. 6B: The reaction time of KB revealed Stroop's effect.

Analyses of single case

Although the correlation between reaction time difference on forward condition and age was 0.36, it was apparently driven by the oldest participant perform an extreme higher score. And the correlation between reaction time difference on backward condition and age was only 0.27.

Therefore, age would not be taken as covariate in this analysis. There was no significant difference found between KB and controls in this task. (Forward: KB's = 124, $z = 0.32$, $p = 0.38$; Backward: KB's = 199.5, $z = 0.28$, $p = 0.40$; the difference between forward and backward: $p = 0.48$, 95% CI = 25.67% to 70.01%) (Figure 6B).

DISCUSSION

The case with a long history of deliberate mirror writing participated in the four tasks to help researchers understand the role of perception and motor programme in mirror writing. It was

found significant differences between KB and control group in the two mental rotation tasks for both perceptual and motor hypotheses, but no significant differences in the Stroop's and Navon's tasks.

First of all, it was showed in the control samples that the Stroop's effect existed when the colour words were printed both forward and mirror-reversed, but was smaller in the latter condition. And the effects of two conditions observed from KB were within the normal range of control data. On the other hand, the results of control group did not show the expected Navon's effect even when the global letters were printed forward. This was because of the effect being more variable in our participants. Although the control data did not have a robust Navon's effect, the result of ANOVA for KB's data presented the significant main effect of reflection and the significant interaction of reflection by reflection. Smaller and non-significant difference in the condition of reversed global letters, this was the result expected from control data. Summary of the results of Stroop's and Navon's tasks suggested no evidence for mirror engrams existed for deliberate mirror writing. Even though with a tremendous exposed to mirror-reversed characters, KB was exempted from the interference of reversed words/letters.

In the mental rotation task of alphanumeric characters, control data presented the pattern of mental rotation task that reaction times increasing with the rotation departure from upright. And there was no speed accuracy trade off as the pattern of accuracy rate was opposite. To analysis KB's data, there was a significant lower accuracy rate to mirror-reversed conditions. With a further checking of the data, however, this consequence was derived from the extremely low accuracy (in fact, it was 0) in the conditions with stimuli as reversed letter "J". If only calculate the subset data of reversed character conditions without J, the accuracy rate could raise from 66.7 % to 88.9%, which was very close to the mean of 88.3% of control group. The possible interpretation of this sounded strange result would be discussed later.

Meanwhile, the analysis of reaction times revealed significantly faster judging for backward

characters in KB than in controls. This difference would be more interesting only when the contrast between forward and backward characters was lower in KB than in control people. Although the test for this dissociation was not significant, it could be seen from the data and the plot (Figure 4D) that the two sets of logarithmic reaction times was almost the same (KB's means for the forward and backward characters were 6.81 and 6.80 respectively). It was not expected that the reaction times of the backward condition would be lower than the forward condition. Besides, the ANOVA analysis of control data had showed a significant effect on reflection (7.02 vs. 7.32). Therefore, the non-significant result could be attributed to the "floor effect" of the contrast between two conditions. And the following discussion would base on the fact that the times needed for judging the forward characters and backward characters were different in control group while were not different for KB.

In the interpretation of previous study, the longer judging times for backward letters were though as the cost of considering and rejecting the normal image first, before going to response the character as a mirrored form (Corballis & McMaster, 1996). In this situation, KB's faster responses to the mirrored stimuli and no time difference from responses of normal stimuli would be considered as the existence for both kinds of engrams, which enable a parallel processing of both reflections during the task.

In the mental rotation task of body parts, control data had also presented the pattern of mental rotation task. And no speed accuracy trade off was observed. In the single case analysis, KB performed significantly worse than controls in hand conditions, but not in the foot conditions. Besides, the dissociation between two conditions was also significant. Even though some of the participants in control group showed poor performances on lateral judging of hand images, they were accompanied by poor performance on foot images (Figure 3E). There was a high degree of correlation ($r = .82$) between the accuracy rate of two effectors. The judging errors observed in these participants might be associated with a more general impairment on the

motor programme accounted for mental rotation of body parts. KB, in contrast, had a deficit of distinguishing right side body from left side body specific to the hand stimuli. This was, therefore, thought to be related to the mirror writing behaviour conducted by his hands.

In most of the motor scripts conducted by hands used in the daily life, the movements could be run in either direction and produced by both hands, for example, turning a door knob. These movements were referred as non-specific mirrored motor conduction (Della Sala & Cubelli, 2007). Grapho-motor programme, on the other hand, was more complicate, and for most of people, specific to one side of effector with particular direction. Intended to practice this motor script with both hands might invoke different underlying mechanisms from other non-specific mirrored motor functions. In the view of ipsilateral control of grapho-motor programme, writing with both hands was sharing one motor programme. Without transforming the direction of conducting motor script, the non-dominant hand would produce a form of mirror writing. As KB reported himself starting learning to write with right hand, it was likely that his practice of left hand mirror writing was to try to directly conduct the right hand motor programme on the left hand.

When doing the mental rotation task of body parts, the corresponding motor area would be activated for simulating the real movements in mind (de Lange et al., 2006). Participants could correctly tell which side of the body parts was presented by the activation of this simulation in the brain. Therefore, the failure of judging laterality of hands in KB could be interpreted as the co-activation of the corresponding motor area for both sides of hands. That is, every time when KB doing the mirror writing with his left hand, he told his brain to invoke the grapho-motor programme of right hand, and conducted with his left hand. Or it could be vice versa when he used his right hand to mirror write and used his left hand to write in the canonical way. For a long period of over practice, intention of moving one would, at the mean time, activate the motor programme of the other hand. Consequently, when KB was asked to judge whether a picture of hand was a left or right image, intention of simulating one side of his hand would

actually have the neural activation for both hands. As a result, he could not benefit from the activation of the corresponding brain activity of the specific side of hand, which was observed in the normal participants in de Lange et al.'s (2006) study, and result in the low accuracy in judging hand laterality.

This interpretation was based on that there was one motor programme shared by two hands. And it was harder to infer with the view of contralaterally controls. As if the mirror writing was derive from the bilaterally stored two grapho-motor programmes, KB's over practice on mirror writing would not necessary invoke the motor activation for the other hand, which was thought being related to the confusion of laterality in mental rotation task of hand images.

As from EHI score that K.B. was a left-hander, he might find that mirror writing with his left hand easy to conduct, and the movement was going from left to right (Swinnen & Wenderoth, 2004). And instead of learning a series of new motor scripts, this activity was just to apply what he had learned with right hand. The similar thought was also reported on other case. For example, in the case-study of left unilateral mirror writing by Angelillo et al. (2010), the patient answered to the question why mirror write while being unable to read as "this is the natural left hand writing style". According to this viewpoint, motor program hypothesis would however be inferred as a downstream implementation of the letters and words, and have no predictions on mirror reading (Gottfried, 2003). The perceptual hypothesis, in contrast, would be expected to associate with mirror reading because the writing mirror error came from the mirror engrams in mind (Della Sala & Cubelli, 2007). Under this point, the two hypotheses of perception and motor programme would seem to be alternative to each other. However, it was observed significant difference between KB and controls in both kinds of mental rotation task.

Back to KB's strange response to the letter J in the mental rotation task, all the mirrored J were judged as normal, and he even incorrectly judged the two out five normal J presented in angle 0 degree. The hypothesis of spatial orientation confusion, might take this result as an example of

orientation/direction confusion. But since there was no report of any this kind of confusion by KB (besides, in the literature of patients with orientation/direction confusion would also show deficit with non-verbal stimuli (Delle Sala, & Cubelli, 2007)), and this was happened only to the specific stimulus, it was better to consider the characteristic of this letter.

Considering the writing script of letter J, the major feature was the hook-like stroke writing from right to left. It was opposite to most of the English and German letters which would be written from left to right. This situation was similar to the Chinese and Japanese characters in which, contrast to the sentences were traditionally written from right to left, the direction of the writing motor scripts of a single character, was actually moving from left to right. It was possible that the error of judging backward letter J as a normal letter was affected by the direction of writing movement of backward J being congruent with the direction of the language, moreover, also being congruent with the more natural moving direction for right-handers from left to right. And this interpretation was corresponded to the observation of higher prevalence of mirror writing in left-handers whose native language were traditionally written from right to left (Schott & Schott, 2004). If this was true, then KB's behaviour to letter J could be an executive directional confusion from over applying grapho-motor programme to different directions, which would be more prone to support the motor hypothesis.

The interpretation of executive directional confusion, on the other hand, could also be linked to the theory of directional apraxia proposed by Della Sala and Cubelli (2007). In this theory, KB's deliberate mirror writing could be contributed to two resources: the engrams of letters (or words) stored in the brain (no matter there was a mirrored version or not); and the downstream directional control of motor program conduction. Merely that, the configuration of writing in KB was neither unestablished nor damaged by brain injury, but he could handle the both ways and used with his writing, as KB was able to used his both hands for conventional and mirror writing.

The experiments chosen in this study were to discuss the role of perception and motor program, thus, only single digits and letters were used in mental rotation task. According to Della Sala and Cubelli (2007), to clarify KB's mirror writing between the hypotheses of motor programme conduction and directional apraxia, more investigation on mirror writing of single letter and of whole words would be needed in the future.

Moreover, mirror writing accompanied with and without mirror reading might indicate different underlying mechanisms. For example, the case reported by Gottfried et al. (2003) had mirror writing behaviour more than eight years and was accompanied by mirror reading (perform better when read words printed mirror-reversed than words in normal fashion). Compared to many of patients whose mirror writing faded away, this patient's mirror writing was thought to be lasting for this long time because of the preference of reading mirror words. KB, in contrast, had even longer history of mirror writing, but still did not show capable of mirror reading.

In summary, the results from the special condition of letter J and the mental rotation of body parts suggested that KB's mirror writing from the over practice of two hands conducting the same grapho-motor programme had led to a co-activation of neural activity for both hands as well as an confusion of the leftward letter. This results of motor programme processing might alternatively reveal the causes of unintentional mirror writing being a more motor based processing. However, we still could not rule out the effect of mirrored engrams. Although there was no significant results in the Stroop's and Navon's task, KB had no difference in the reaction times between backward and forward characters was an obvious evidence that KB might process the backward characters differently from normal control people.

REFERENCES

- Angelillo, V.G., De Lucia, N., Trojano, L., & Grossi, D. (2010). Persistent left unilateral mirror writing: A neuropsychological case study. *Brain and Language*, 114, 157-163. doi:10.1016/j.bandl.2010.04.003
- Buxbaum, L. J., Coslett, H. B., Schall, R. R., McNally, B., & Goldberg, G. (1993). Hemispatial factors in mirror writing. *Neuropsychologia*, 12, 1417-1421. doi:10.1016/0028-3932(93)90108-C
- Crawford, J.R. & Garthwaite, P.H. (2007). Comparison of a single case to a control or normative sample in neuropsychology: Development of a Bayesian approach. *Cognitive Neuropsychology*, 24, 343-372.
- Crawford, J. R., Garthwaite, P. H., and Ryan, K. (2011). Comparing a single case to a control sample: Testing for neuropsychological deficits and dissociations in the presence of covariates. *Cortex*, in press.
- Cooper, L. A. & Shepard, R. N. (1973). The time required to prepare for a rotated stimulus. *Memory & Cognition*, 1, 246-250.
- Corballis, M. C., & McMaster, H. (1996). The roles of stimulus-response compatibility and mental rotation in mirror-image and left-right decisions. *Canadian Journal of Experimental Psychology*, 50, 397-401.
- de Lange, F. P., Helmich, R.C., & Toni, I. (2006). Posture influences motor imagery: an fMRI study. *Neuroimage*, 33, 609-617.
- Della Sala, S., & Cubelli, R. (2007). "Directional apraxia": A unitary account of mirror writing following brain injury or as found in normal young children. *Journal of Neuropsychology*, 1, 3-26.
- Fiorio, M., Tinazzi, M., & Aglioti, S. M. (2006). Selective impairment of hand mental rotation in patients with focal hand dystonia. *Brain*, 129, 47-54.

- Funk, M. & Brugger, P. (2008). Mental rotation of congenitally absent hands. *Journal of the International Neuropsychological Society*, 14, 81-89.
- Gottfried, J. A., Sancar, F., & Chatterjee, A. (2003). Acquired mirror writing and reading: Evidence for reflected graphemic representations. *Neuropsychologia*, 41, 96–107.
- Heilman, K. M., Howell, G., Valenstein, E., & Rothi, L. (1980). Mirror-reading and writing in association with right-left spatial disorientation. *Journal of Neurology, Neurosurgery and Psychiatry*, 43, 774-780.
- Koriat A. & Norman, J. (1989). Why is word recognition impaired by disorientation while the identification of single letters is not? *Human Perception and Performance*, 15, 153-163.
- Moris, G., Quirce, R., Berciano, J., & Pascual, J. (1997). Bimanual mirror letter writing: A post-traumatic case. *Neurologia*, 12, 418–420.
- Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology*, 9, 353-383.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh Inventory. *Neuropsychologia*, 9, 97–113.
- Schott, G. (1999). Mirror writing: Allen's self observations. Lewis Carroll's 'looking glass' letters, and Leonardo da Vinci's maps. *Lancet*, 154, 2158-2161.
- Schott, G. D. (2007). Mirror writing: neurological reflections on an unusual phenomenon. *Journal of Neurology, Neurosurgery and Psychiatry*, 78, 4-13.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18, 643-662.
- Swinnen, S. P., & Wenderoth, N. (2004). Two hands, one brain: cognitive neuroscience of bimanual skill. *Trends in Cognitive Sciences*, 8, 18-25. doi:10.1016/j.tics.2003.10.017
- Tucha, O., Aschenbrenner, S., & Lange, K. W. (2000). Mirror writing and handedness. *Brain and Language*, 73, 432-441.
- Vinckier, F., Naccache, L., Papeix, C., Forget, J., Hahn-Barma, V., Dehaene, S., & Cohen, L.

(2006). “What” and “Where” in word reading: Ventral coding of written revealed by parietal atrophy. *Journal of Cognitive Neuroscience*, 18, 1998-2012.

Winer, B. J. (1962). *Statistical principles in experimental design*. New York, NY: McGraw Hill.